

AHRI Standard 1211 (SI)

2017 Standard for
**Performance Rating
of Variable Frequency
Drives**



2111 Wilson Boulevard, Suite 500
Arlington, VA 22201, USA
www.ahrinet.org
PH 703.524.8800
FX 703.562.1942

we make life better™

IMPORTANT

SAFETY DISCLAIMER

AHRI does not set safety standards and does not certify or guarantee the safety of any products, components or systems designed, tested, rated, installed or operated in accordance with this standard/guideline. It is strongly recommended that products be designed, constructed, assembled, installed and operated in accordance with nationally recognized safety standards and code requirements appropriate for products covered by this standard/guideline.

AHRI uses its best efforts to develop standards/guidelines employing state-of-the-art and accepted industry practices. AHRI does not certify or guarantee that any tests conducted under its standards/guidelines will be non-hazardous or free from risk.

Note:

This standard supersedes ANSI/AHRI Standard 1211 (SI)-2011 with Addenda 1 and 2

For I-P ratings, see AHRI Standard 1210 (I-P)-2017

TABLE OF CONTENTS

| SECTION | | PAGE |
|------------|---|------|
| Section 1. | Purpose..... | 1 |
| Section 2. | Scope..... | 1 |
| Section 3. | Definitions..... | 1 |
| Section 4. | Classifications | 3 |
| Section 5. | General Test Requirements | 3 |
| Section 6. | Rating Requirements..... | 6 |
| Section 7. | Minimum Data Requirements for Published Requirements..... | 7 |
| Section 8. | Marking and Nameplate Data | 7 |
| Section 9. | Conformance Conditions. | 7 |

TABLES

| | | |
|----------|--|---|
| Table 1. | Voltage and Power Classifications..... | 3 |
| Table 2. | Speed/Torque Test Points for Drive System Efficiency and Motor Stress Insulation Tests | 4 |
| Table 3. | VFD to Motor Conductor Sizes | 4 |

APPENDICES

| | | |
|-------------|--|---|
| Appendix A. | References – Normative..... | 8 |
| Appendix B. | References – Informative | 8 |
| Appendix C. | Method of Testing Variable Frequency Drives - Normative..... | 9 |

FIGURES FOR APPENDICES

| | | |
|------------|---|----|
| Figure C1. | Test Set-up for Drive System Efficiency and Power Line Harmonics Test Methods | 10 |
|------------|---|----|

PERFORMANCE RATING OF VARIABLE FREQUENCY DRIVES

Section 1. Purpose

1.1 *Purpose.* The purpose of this standard is to establish for Variable Frequency Drives (VFDs): definitions; classifications; general test requirements; rating requirements; minimum data requirements for Published Ratings; marking and nameplate data; and conformance conditions.

1.1.1 *Intent.* This standard is intended for the guidance of the industry, including manufacturers, engineers, installers, contractors and users.

1.1.2 *Review and Amendment.* This standard is subject to review and amendment as technology advances.

Section 2. Scope

2.1 *Scope.* This standard applies, within the heating, ventilating, air-conditioning and refrigeration (HVACR) context, to 60 Hz VFDs used in the control of asynchronous induction motors. The range includes all those found within a building including: low voltage (≤ 600 V) and drives that are stand alone, not mechanically integrated into motors.

2.2 *Exclusions.* This standard does not apply to VFDs applied to motors other than those listed above.

Section 3. Definitions

All terms in this document shall follow the standard industry definitions in the ASHRAE Terminology website (<https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology>), unless otherwise defined in this section.

3.1 *Carrier Switching Frequency.* The frequency at which the power output devices of a VFD are switched on and off.

3.2 *Constant Torque (CT).* Applications where the torque requirement of the driven load remains constant or nearly so over the normal speed range of use. Positive-displacement pumps and reciprocating compressors are examples of constant-torque loads.

3.3 *Drive System Efficiency.* Ratio of the output power from the motor to the input power of the VFD including motor and VFD losses.

3.4 *Equipment Under Test (EUT).* Test sample.

3.5 *Fundamental Current.* Root mean square (RMS) current of the first harmonic (Power Line Frequency).

3.6 *Impedance.* The measure of the opposition that a circuit presents to current.

3.6.1 *Source Impedance.* The short-circuit power at the point of common coupling (PCC), divided by the rated apparent power of the drive and as defined in IEC Standard 61000-3-12, Section 3.14 Subsection C.

3.7 *Motor Insulation Stress.* The voltage stress placed on a motor's insulation due to high Peak Voltages and short-rise times that occur when the motor is driven by a VFD.

3.8 *Motor Thermal Equilibrium.* When the observed temperature rise of the motor winding does not vary more than 1K over a period of 30 minutes, or when the observed motor frame or core temperature rise does not vary more than 1K over a period of 60 minutes.

3.9 *Peak Voltage.* The maximum instantaneous voltage measured at a motor's terminals when operated from a VFD.

3.10 *Percent Speed.* The ratio of the measured speed to motor nameplate speed, %.

- 3.11** *Percent Torque.* The ratio of the measured torque to the motor torque, %.
- 3.12** *Power Line Frequency.* The alternating current (AC) frequency of the power supplied to the VFD.
- 3.13** *Power Line Harmonics.* Components of the power line voltage and current at the input of the VFD that are integer multiples of the fundamental sinusoidal frequency of the power source (example 50 Hz).
- 3.14** *Published Rating.* A rating of the assigned values of those performance characteristics, under stated Rating Conditions, by which a unit may be chosen to fit its application. These values apply to all units of like nominal size and type (identification) produced by the same manufacturer. As used herein, the term Published Rating includes the rating of all performance characteristics shown on the unit or published in specifications, advertising or other literature controlled by the manufacturer, at stated Rating Conditions.
- 3.14.1** *Application Rating.* A rating based on tests performed at application Rating Conditions (other than Standard Rating Conditions).
- 3.14.2** *Standard Rating.* A rating based on tests performed at Standard Rating Conditions.
- 3.15** *Rating Conditions.* Any set of operating conditions under which a single level of performance results and which causes only that level of performance to occur (e.g. line voltage, ambient temperature).
- 3.15.1** *Standard Rating Conditions.* Rating Conditions used as the basis of comparison for performance characteristics.
- 3.16** *"Shall" or "Should."* "Shall" or "should" shall be interpreted as follows:
- 3.16.1** *Shall.* Where "shall" or "shall not" is used for a provision, that provision is mandatory if compliance with the standard is claimed.
- 3.16.2** *Should.* "Should" is used to indicate provisions which are not mandatory but are desirable as good practice.
- 3.17** *Supply Voltage (V_s).* The line to line input voltage to the equipment at time of testing.
- 3.18** *System Loss ($Loss_{sys}$).* The combination of electrical and mechanical losses represented by the difference between input power to the drive and output power from the motor.
- 3.19** *Total Harmonic Current Distortion (THD_i).* A measure of power line current distortion that sums the contributions of the individual harmonics.
- 3.20** *Variable Frequency Drive (VFD).* A power electronic device that regulates the speed of an alternating current (AC) motor by adjusting the frequency and the voltage of the electrical power supplied to the motor.
- 3.21** *Variable Torque (VT).* Applications where the torque requirement of the driven load is reduced as speed is reduced. Centrifugal fans and pumps are examples of variable-torque (VT) loads.
- 3.22** *Voltage Rise Time.* The time required for the voltage to increase, measured at the motor terminals when operated from a VFD, from 10% to 90% of the VFD steady state DC bus voltage.

Section 4. Classifications

4.1 *Classifications.* VFDs falling within the scope of this standard are defined in Table 1.

| Table 1. Voltage and Power Classifications | | | |
|---|------------|------------|------------|
| VFD Voltage Rating (V) | 200 to 240 | 380 to 480 | 550 to 600 |
| Supply Voltage V_s (V) | 208 | 460 | 575 |
| Power (hp) | 1.0 | 1.0 | 1.0 |
| | 2.0 | 2.0 | 2.0 |
| | 3.0 | 3.0 | 3.0 |
| | 5.0 | 5.0 | 5.0 |
| | 7.5 | 7.5 | 7.5 |
| | 10.0 | 10.0 | 10.0 |
| | 15.0 | 15.0 | 15.0 |
| | 20.0 | 20.0 | 20.0 |
| | 25.0 | 25.0 | 25.0 |
| | - | 30.0 | 30.0 |
| | - | 40.0 | 40.0 |
| | - | 50.0 | 50.0 |
| | - | 60.0 | 60.0 |
| - | - | 75.0 | |

Section 5. General Test Requirements

5.1 *Test Requirements.* VFDs shall be tested in accordance with the procedures set forth in Appendix C of this standard.

5.1.1 *Electrical Conditions.* Tests shall be performed at the voltages listed above in Table 1 per the rated Voltage Class and frequency of the motor drive systems unless otherwise specified in this standard.

Note: Since motor drive systems with a 230 V rating are commonly operated at a utilization voltage of 208 V, then all 230 V rated motors shall be tested at 208 V Class.

5.1.2 *Power Source Requirements.* The power source shall meet the following requirements while measurements are being taken during testing:

5.1.2.1 The power source voltage and frequency at the VFD input terminals shall be maintained during the test at the rated voltage of the motor (e.g. 208, 460, 575 V) and rated frequency with a tolerance of $\pm 0.5\%$.

5.1.2.2 The power source-voltage unbalance during the test shall not exceed 0.5%. Phase-voltage unbalance shall be determined as defined in IEEE Standard 141.

5.1.2.3 The source impedance of the power supply shall not exceed 1%.

5.1.3 *Test Motor.* The motor selected for testing shall be a NEMA design B four-pole matching the VFD voltage and power.

5.1.4 *Speed/Load Testing Points.* Table 2 shows the various speed/load combinations where measurements are taken for Drive System Efficiency and Motor Insulation Stress. Power Line Harmonics will be tested at 100% speed and torque. Details of the procedure for each test are presented in Appendix C.

| Table 2. Speed/Torque Test Points for Drive System Efficiency and Motor Stress Insulation Tests ^{1,2} | | | | | |
|--|------|----------------|-----|-----|-------|
| | | Percent Torque | | | |
| | | 16% | 25% | 56% | 100% |
| Percent Speed | 40% | VT | | | CT |
| | 50% | | VT | | CT |
| | 75% | | | VT | CT |
| | 100% | | | | CT/VT |

Notes:
 1. Output frequency or other readouts from the VFD shall not be used to determine percent speed.
 2. Only those cells that contain CT or VT are test points

5.1.5 Drive Settings. The VFD shall be set up according to the manufacturer’s instructional and operational manual included with the product. Manufacturers shall also provide parameter set-up summary including at minimum:

- 5.1.5.1** Carrier switching frequency, Hz
- 5.1.5.2** Max frequency, Hz
- 5.1.5.3** Max output voltage, V
- 5.1.5.4** Motor control method (i.e. V/f ratio, sensor less vector, etc.)
- 5.1.5.5** Load profile setting (Constant Torque, Variable Torque, etc.)
- 5.1.5.6** Saving energy mode (if used)

Note: One summary sheet shall be supplied for Constant Torque and a separate one for Variable Torque testing. Deviation from the resulting settings, such as Carrier Switching Frequency or load torque curves, for the purpose of optimizing test results shall not be permitted. For example, parameters dealing with carrier frequency shall be unchanged from one test to the other.

5.1.6 Motor Wires. The three load current carrying conductors between the VFD and motor shall be part of a shielded cable intended for VFD/motor applications. This cable shall be a symmetrical type having copper conductors, type XHHW with 2 spiral insulations on the current carrying conductors, three smaller ground wires and an overall jacket made of type XLPE insulation. The cable shall be sized per Table 3. Where the cable is not available with the current carrying conductors in the size shown in Table 3, the next larger size shall be used.

| Table 3. VFD to Motor Conductor Sizes | | | | | | |
|---------------------------------------|------------------|---------------|------------------|---------------|------------------|---------------|
| Power (kW) | 208 V | | 460 V | | 575 V | |
| | Wire Gauge (AWG) | Diameter (mm) | Wire Gauge (AWG) | Diameter (mm) | Wire Gauge (AWG) | Diameter (mm) |
| 0.75 | 14 | 1.63 | 14 | 1.63 | 14 | 1.63 |
| 1.50 | 14 | 1.63 | 14 | 1.63 | 14 | 1.63 |
| 2.25 | 14 | 1.63 | 14 | 1.63 | 14 | 1.63 |
| 3.75 | 12 | 2.05 | 14 | 1.63 | 14 | 1.63 |
| 5.60 | 10 | 2.59 | 14 | 1.63 | 14 | 1.63 |
| 7.45 | 8 | 3.26 | 14 | 1.63 | 14 | 1.63 |
| 11.20 | 6 | 4.11 | 10 | 2.59 | 12 | 2.05 |
| 14.90 | 4 | 5.19 | 8 | 3.26 | 10 | 2.59 |
| 18.65 | 3 | 5.83 | 8 | 3.26 | 8 | 3.26 |
| 22.35 | 2 | 6.54 | 6 | 4.11 | 8 | 3.26 |
| 29.80 | - | - | 4 | 5.19 | 6 | 4.11 |
| 37.30 | - | - | 3 | 5.83 | 4 | 5.19 |
| 44.75 | - | - | 2 | 6.54 | 3 | 5.83 |
| 55.90 | - | - | - | - | 2 | 6.54 |

5.1.7 Motor Thermal Equilibrium. Apply the rated voltage and frequency to the drive and full load torque to the motor until thermal equilibrium is reached. Individual test steps in Appendix C. shall indicate whether they are to be conducted at this thermal stabilization temperature.

5.1.8 Ambient Temperatures. The ambient temperature at the VFD vicinity (approximately 1 m away and not in the exhaust air stream of the VFD) during testing shall be maintained within the range of 21°C - 27°C.

5.1.9 Reference Equations.

5.1.9.1 The Total Harmonic Current Distortion (THD_i) shall be calculated as follows:

$$THD_i = \sqrt{\sum_{n=2}^{50} \left(\frac{I_n}{I_1}\right)^2} \cdot 100 \quad 1$$

Where:

I₁ = Fundamental Current, A (amps)
 I_n = the value of an individual harmonic current, A (amps)
 THD_i = Total Harmonic Current Distortion, %

5.1.9.2 The output power (P_{out}) shall be calculated as follows:

$$P_{out} = \frac{\tau \cdot \omega}{K} \quad 2$$

Where:

ω = Speed, rpm
 τ = Torque, N · m
 P_{out} = Output power, hp
 K = 9549 N · m rpm / hp

5.1.9.3 The Drive System Efficiency (η_{sys}) shall be calculated as follows:

$$\eta_{sys} = \frac{P_{out}}{P_{in}} \cdot 100 \quad 3$$

Where:

P_{in} = Input power, hp
 P_{out} = Output power, hp
 η_{sys} = Drive System Efficiency, %

5.1.9.4 The rated motor torque (τ_{mtr}) shall be calculated as follows:

$$\tau_{mtr} = \frac{P_{mtr} \cdot K}{\omega_{mtr}} \quad 4$$

Where:

ω_{mtr} = Motor nameplate speed, rpm
 P_{mtr} = Motor nameplate output power, hp
 τ_{mtr} = Rated motor torque, N.m
 K = 9549 N · m rpm / hp

5.1.9.5 The Impedance (Z) shall be calculated as follows:

$$Z = \frac{I_{rated_{VFD}}}{I_{sc_{source}}} \cdot 100 \quad 5$$

Where:

$I_{ratedVFD}$ = VFD rated current, A
 $I_{scsource}$ = Source short circuit current, A
 Z = Impedance, %

5.1.9.6 The System Losses of the Drive System Efficiency shall be calculated as follows:

$$Loss_{sys} = 100 - \eta_{sys} \quad 6$$

Where:

$Loss_{sys}$ = System Losses, %
 η_{sys} = Drive System Efficiency, %

Section 6. Rating Requirements

6.1 *Published Ratings.* Published Ratings shall include Drive System Efficiency, Motor Insulation Stress, and Power Line Harmonics.

6.1.1 Drive System Efficiency shall be expressed in terms of % and stated to the nearest 0.5 %.

6.1.2 Motor Insulation Stress shall be expressed in terms of Peak Voltage and Voltage Rise Time stated to the nearest 10 V_{peak} and 0.01 μsec, respectively.

6.1.3 Power Line Harmonic currents shall include the following parameters below, expressed in terms of % and stated to the nearest 1%.

6.1.3.1 Individual Harmonic Currents (I_{2-50}/I_1) at 100% load, based on the arithmetic average of the three phase line harmonic currents.

6.1.3.2 Total Harmonic Current Distortion (THD_i)

6.2 *Standard Ratings.* All Standard Ratings shall be verified by tests in accordance with Section 5.

6.3 *Application Ratings.* Ratings based on data determined by test requirements prescribed in Section 5 and conducted in accordance with the method of testing described in Appendix C.

6.4 *Tolerances.* Measured test results following the procedures in Appendix C, shall meet the following rating tolerances:

6.4.1 *Drive System Efficiency.* The System Losses of the measured Drive System Efficiency of any manufactured unit shall not be greater than 120% of the System Losses of the published Drive System Efficiency in percent (For example, if published Drive System Efficiency is 90%, the System Losses of the published Drive System Efficiency is 10% as determined from Equation 6. The measured Drive System Efficiency cannot be less than 88% or the System Losses of the measured Drive System Efficiency cannot be greater than 12%).

6.4.2 *Motor Insulation Stress.* The measured Peak Voltage of any manufactured unit shall not be more than 10% higher than the certified Peak Voltage and the measured Voltage Rise Time of any manufactured unit shall not be less than 0.03 μsec compared to the certified Voltage Rise Time (For example, if published rating of Peak Voltage is 1,000v, the measured cannot exceed 1,100v. If the published rating of Voltage Rise Time is 0.10μsec, the measured cannot be less than 0.07μsec).

6.4.3 *Power Line Harmonics.* The published rating of Total Harmonic Current Distortion and each of its harmonics at maximum load shall not be more than 2% of the corresponding measured value and shall be reported with a source impedance of 1% (e.g. If published rating is 40%, then 42% would be acceptable).

Section 7. Minimum Data Requirements for Published Ratings

7.1 *Minimum Data Requirements for Published Ratings.* As a minimum, Published Ratings shall include Standard Ratings. The following information shall be published for all Standard Ratings:

- 7.1.1** Power Classification, hp, as determined by Table 1
- 7.1.2** Supply Voltage V_s , V, as determined by Table 1
- 7.1.3** Drive System Efficiency, %, as determined by Section 5.1.9.3 and measured at points defined in Table 2
- 7.1.4** Motor Insulation Stress Peak Voltage, V_{peak} , as defined by Sections 3.9 and 3.22
- 7.1.5** Motor Insulation Stress Voltage Rise Time, μsecs , as defined by Sections 3.9 and 3.22
- 7.1.6** Power Line Harmonics, Total Harmonic Current Distortion, %, as defined by Section 3.19 and 5.1.9.1
- 7.1.7** Individual Power Line Harmonics of Fundamental Current, 1st through 50th harmonic, % as defined by Section 5.1.9.1 and 6.1.3.1

7.2 *Rating Claims.* All claims to ratings within the scope of this standard shall include the statement “Rated in accordance with AHRI Standard 1211 (SI).” All claims to ratings outside the scope of this standard shall include the statement “Outside the scope of AHRI Standard 1211 (SI).” Wherever Application Ratings are published or printed, they shall include a statement of the conditions at which the ratings apply.

Section 8. Marking and Nameplate Data

8.1 *Marking and Nameplate Data.* As a minimum, the nameplate shall display the manufacturer’s name, model designation, and electrical characteristics. Nameplate voltages for 60Hz systems shall include one or more of the equipment nameplate voltage ratings shown in Table 1 of AHRI Standard 110. Nameplate voltages for 50 Hz systems shall include one or more of the utilization voltages shown in Table 1 of IEC Standard 60038.

Section 9. Conformance Conditions

9.1 *Conformance.* While conformance with this standard is voluntary, conformance shall not be claimed or implied for products or equipment within the standard’s *Purpose* (Section 1) and *Scope* (Section 2) unless such product claims meet all the requirements of the standard and all of the testing and rating requirements are measured and reported in complete compliance with the standard. Any product that has not met all the requirements of the standard cannot reference, state, or acknowledge the standard in any written, oral, or electronic communication .

APPENDIX A. REFERENCES – NORMATIVE

A1 Listed here are all standards, handbooks, and other publications essential to the formation and implementation of the standard. All references in this appendix are considered as part of this standard.

A1.1 AHRI Standard. 110-2016, Air-Conditioning and Refrigerating Equipment Nameplate Voltages, 2016, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Blvd, Suite 500, Arlington, VA 22201, U.S.A.

A1.2 ANSI/ASHRAE Standard 41.1-2013 (RA 06), *Standard Method for Temperature Measurement*, 2013, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle N.E., Atlanta, GA 30329, U.S.A.

A1.3 ASHRAE Terminology, <https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology>, 2017, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.4 IEC Standard 60038-2009, *IEC Standard Voltages*, 2009, International Electrotechnical Commission, rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland.

A1.5 IEC Standard 61000-3-2-2014, *Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*, 2014, International Electrotechnical Commission, rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland.

A1.6 IEC Standard 61000-3-12-2011, *Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase*, 2011, International Electrotechnical Commission, rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland.

A1.7 IEC Standard 61000-4-7-2002, *Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*, 2002, International Electrotechnical Commission, rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland.

A1.8 IEEE Standard 141-1993, *IEEE Recommended Practice for Electric Power Distribution for Industrial Plants*, 1993, IEEE, 3 Park Avenue, 17th Floor, New York, NY 10016-5997

A1.9 ISO/IEC Standard 17025:2005, *General Requirements for the Competence of Testing and Calibration Laboratories*, 2005, 1 ch. De las Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland

A1.10 *National Electrical Code Handbook (NEC)*, 2017, National Fire Prevention Association, 1 Batterymarch Park, Quincy, Massachusetts, 02169-7471

A1.11 NEMA MG 1-2016, *Motors and Generators*, 2016, National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1752, Rosslyn, Virginia 22209

APPENDIX B. REFERENCES – INFORMATIVE

B1 Listed here are standards, handbooks, and other publications which may provide useful information and background but are not considered essential. References in this appendix are not considered part of the standard.

None.

APPENDIX C. METHODS OF TESTING VARIABLE FREQUENCY DRIVES – NORMATIVE

C1 *Purpose.* The purpose of this appendix is to specify for VFDs: instrumentation, facilities and equipment, test procedures and methods of calculation for determining their efficiency and related performance.

C2 *Scope.* The test methods are provided for use with VFDs and motor combinations.

C2.1 *Exclusions.* This standard is not applicable to tests conducted in the field or on the production line.

C3 *Installation and Operation.*

C3.1 *Installation.* The VFD shall be installed and operated per the manufacturer's installation & operation manual (IOM) with modifications as required for a testing environment.

C3.2 *Drive Settings.* The drive shall be set up according to the manufacturer's IOM as submitted at time of testing. The manufacturer shall also provide a summary of the required instructions for variable and Constant Torque. This summary sheet will include at minimum parameters relating to: carrier frequency, maximum frequency, maximum output voltage, V/f ratio, and output algorithm. One data sheet can be supplied for Constant Torque and a separate one for Variable Torque testing. Deviation from the resulting settings, such as carrier frequency or load torque curves, for the purpose of optimizing test results shall not be permitted. For example, parameters dealing with carrier frequency shall be unchanged from one test to the other.

C4 *Instrumentation Accuracy Requirements and Certification.*

C4.1 *Electrical Measurements.* For the drive system efficiency and power line harmonics tests, the instruments shall have an accuracy of $\pm 0.2\%$ of full scale at the fundamental supply source frequency and shall be capable of measuring current, voltage and real power at least up to the 50th harmonic of fundamental supply source frequency and shall be designed as per IEC Standard 61000-4-7. When more than one instrument is required to measure a parameter, accuracy of each individual instrument shall be multiplied together to calculate the total accuracy for this specific measurement. Moreover, in addition to these requirements, for the motor insulation stress test, the instruments shall be capable of measuring the Peak Voltage and the VFD DC bus voltage with an accuracy of $\pm 1\%$ and the Voltage Rise Time with an accuracy of $\pm 10\%$.

C4.2 *Mechanical Measurements.* Equipment used to set and measure motor torque shall have an accuracy of $\pm 0.2\%$ of full scale value. When the torque measurement is made between the test motor and the dynamometer, the dynamometer losses do not affect the measurement, which indicates that dynamometer correction is not necessary. If other methods are used, dynamometer correction shall be determined and applied to all torque measurements. Motor shaft rotational speed shall be measured with instrumentation providing accuracy of ± 1 rpm.

C4.3 *Time Measurements.* Elapsed time measurements shall be made with instruments having an accuracy of $\pm 0.5\%$ of the value being observed.

C4.4 *Temperature Measurements.* Temperature measurements shall be made in accordance with ANSI/ASHRAE Standard 41.1 with instruments having an accuracy of $\pm 1.0^\circ\text{K}$. The smallest graduation is to represent a maximum of 0.1°K .

C4.5 *Certification of Instrument Calibration.* Test instrumentation calibration shall be traceable to national standards and shall be accompanied by a record of calibration, covering the range of its intended use, performed within 12 months of the test. The instrumentation calibration shall have been performed by a certified calibration laboratory per ISO/IEC Standard 17025.

C5 *Test Procedures.*

C5.1 *Test Methods.* The test methods shall be used in determining the Drive System Efficiency, Motor Insulation Stress and Power Line Harmonics.

C5.1.1 *Titles of Test Methods.* The test methods described are:

- C5.1.1.1** Drive System Efficiency and Power Line Harmonics (Section C5.2)
- C5.1.1.2** Motor Insulation Stress (Section C5.3)

C5.2 *Drive System Efficiency and Power Line Harmonics Test Methods.*

C5.2.1 *Drive System Efficiency Test Method.* The Drive System Efficiency shall be determined using the motor specified in Section 5.1.3. The Drive System Efficiency test set-up shall be constructed as shown in Figure C1 and the VFD shall be installed in accordance with the manufacturer’s written instructions.

C5.2.2 *Power Line Harmonics Test Method.* The power line harmonics test determines the relative levels of current and voltage requirements. Current supplied by the power source to a VFD includes harmonics of the 60 Hz fundamental frequency. These harmonic currents, in turn, cause distortion of the power source voltage sine wave, resulting in voltage harmonics. The power line harmonics test set-up shall be constructed as shown in Figure C1 and the VFD shall be installed in accordance with the manufacturer’s written instructions.

C5.2.3 *Test Set-up.* The test set-up is composed of the following components as shown in Figure C1:

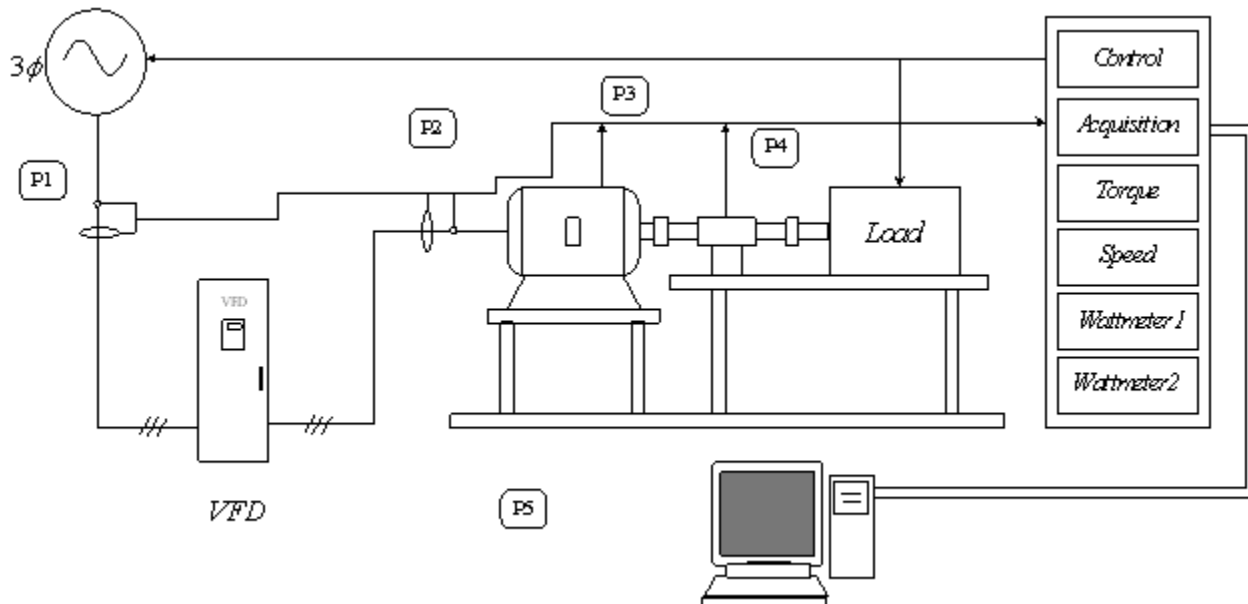


Figure C1. Test Set-up for Drive System Efficiency and Power Line Harmonics Test Methods

C5.2.4 *Measurement Locations.*

- C5.2.4.1** P1. Closest point less than 1 m to input terminals of the VFD.
- C5.2.4.2** P2. Closest point less than 1 m to input terminals of the motor.
- C5.2.4.3** P3. Temperature sensor installed on the motor stator winding out of the cooling air circulation path.
- C5.2.4.4** P4. Torque/speed sensor between the motor and the load.
- C5.2.4.5** P5. Ambient temperature sensor near the cooling air entering the motor.

C5.2.5 *Speed/Load Testing Points.* System efficiency shall be determined for the specified speed/load combinations shown in Table 2.

C5.2.6 *Motor Conductor Length.* The length of the conductors between the VFD and motor for the purpose of performing the Drive System

Efficiency and the power line harmonics tests shall be 6 m.

C5.2.7 *Sample Procedure.*

- C5.2.7.1** Set up equipment per diagram.
- C5.2.7.2** Energize system.
- C5.2.7.3** Run system until Motor Thermal Equilibrium is achieved at rated motor speed/torque load point.
- C5.2.7.4** Record data at points P1, P3, P4, P5.
- C5.2.7.5** Run system at next lower torque point.
- C5.2.7.6** When all torque points at that speed have been recorded, proceed to the next lower speed point.
- C5.2.7.7** Proceed to next voltage category (if necessary).
- C5.2.7.8** Repeat test until complete.

C5.2.8 *Measurements.* When loading the motor, start at the highest load value and move in descending order to the lowest. At any load point, the temperature of the motor stator winding shall be within 10°C of the hottest temperature reading recorded at the rated motor speed/torque load point prior to the recording of any data for this test. A sufficient number of samples over a reasonable period of time shall be recorded and averaged to facilitate good correlation at each load point.

Note: When the EUT has a harmonic spectrum that is varying in time, the harmonic calculation shall use an averaging window of 15 sec to accurately represent the average level of harmonic.

C5.2.9 *Recording Data.* Data to be recorded during the test:

C5.2.9.1 P1.

- C5.2.9.1.1** Power Factor, %
- C5.2.9.1.2** Each line to Line Voltage, V_{rms}
- C5.2.9.1.3** Each line current, A_{rms}
- C5.2.9.1.4** Input Power, kW
- C5.2.9.1.5** Frequency, Hz
- C5.2.9.1.6** Current harmonics, A_{rm} (or in % of the fundamental)

C5.2.9.2 P2.

- C5.2.9.2.1** No data to be collected

C5.2.9.3 P3.

- C5.2.9.3.1** Motor temperature, °C

C5.2.9.4 P4.

- C5.2.9.4.1** Torque, N·m
- C5.2.9.4.2** Speed, rpm

C5.2.9.5 P5.

- C5.2.9.5.1** Ambient temperature, °C

C5.3 *Motor Insulation Stress Test Method.* The motor insulation stress test determines the relative levels of Peak Voltage and voltage rise time measured at the terminals of the test motor. Motors operating on VFDs experience higher levels of Peak Voltage and voltage rise time than when they are operating directly from a 60 Hz power source. These elevated levels create additional stress on the motor insulation system and may result in early insulation failure

and shortened motor life. The motor insulation stress test set-up shall be constructed as shown in Figure C1 and the VFD shall be installed in accordance with the manufacturer’s written instructions.

C5.3.1 Test Set-up. The test set-up is composed of the same components as shown in Figure C1.

C5.3.2 Measurement Points.

- C5.3.2.1** P1. Closest point less than 1 m to input terminals of the VFD.
- C5.3.2.2** P2. Closest point less than 1 m to input terminals of the motor.
- C5.3.2.3** P3. Temperature sensor installed on the motor stator winding out of the cooling air circulation path.
- C5.3.2.4** P4. Torque/Speed sensor between the motor and the load.
- C5.3.2.5** P5. Ambient temperature sensor near the cooling air entering the motor.

C5.3.3 Voltage Categories Tested. Testing shall only be performed on the 480V Class and 600V Class VFD. VFDs having a nominal input voltage rating of 250 VAC or less are exempt from this testing.

C5.3.4 Speed/Load Testing Points. Measurements shall only be taken at rated motor speed and torque.

C5.3.5 Motor Conductor Length. The lengths of the conductors between the VFD and motor have a significant effect on Peak Voltage and voltage rise time. Test measurements shall be taken with each set of conductors representing short, medium and long lengths used in field applications, as follows: 6 m, 15 m, and 30 m.

C5.3.6 Sample Procedure.

- C5.3.6.1** Set up equipment per diagram at short cable length.
- C5.3.6.2** Energize system.
- C5.3.6.3** Run system until motor thermally stabilizes at rated motor speed/torque.
- C5.3.6.4** Record data at points P1, P2, P3, P4, and P5.
- C5.3.6.5** De-energize system.
- C5.3.6.6** Remove cable between VFD and motor in test setup.
- C5.3.6.7** Install next longer cable length ensuring all connections are tight.
- C5.3.6.8** Re-energize system.
- C5.3.6.9** Repeat Steps C5.3.6.4 to C5.3.6.6 until all lengths have been tested.

C5.3.7 Measurements. At any test point, the temperature of the motor stator winding shall be within 10°K of the hottest temperature reading recorded at the rated motor speed/torque load point prior to the recording of any data for this test. A sufficient number of samples over a reasonable period of time shall be recorded and averaged to facilitate good correlation

C5.3.8 Recording Data. Data to be recorded during the test

C5.3.8.1 P1

- C5.3.8.1.1** Each line to line voltage, V_{rms} .
- C5.3.8.1.2** Each line current, A_{rms} .
- C5.3.8.1.2** Input power, kW.
- C5.3.8.1.2** Frequency, Hz.

C5.3.8.2 P2

- C5.3.8.2.1** Peak Voltage, V_{Peak} .
- C5.3.8.2.2** VFD DC Bus voltage, V DC.
- C5.3.8.1.1** Voltage Rise Time, μsec .
- C5.3.8.1.1** Carrier frequency, Hz.
- C5.3.8.1.1** Output frequency, Hz.

C5.3.8.3 P3

C5.3.8.3.1 Motor Temperature, °C.

C5.3.8.4 P4

C5.3.8.4.1 Torque, N·m.

C5.3.8.4.2 Speed, rpm.

C5.3.8.5 P5

C5.3.8.5.1 Ambient Temperature, °C.

C6 *Calculations.*

C6.1 *Total Harmonic Current Distortion.* Total Harmonic Current Distortion shall be measured and calculated per IEC Standard 61000-3-2. The following clarifications and exceptions apply to the usage of this standard for the AHRI Standard:

C6.1.1 *Clarifications.*

C6.1.1.1 This standard shall be applied to determine the actual harmonic distortion levels of the EUT. The pass/fail criteria imposed in the IEC Standard do not apply to this AHRI Standard.

C6.1.1.2 The standard shall be utilized on the US standard, 60 Hz power systems.

C6.1.2 *Exceptions.*

C6.1.2.1 *Point of Common Coupling (PCC).* The PCC for this standard and test measurement shall be the closest available point to the input of the EUT.

C6.1.2.2 This standard covers three phase equipment with a current unbalance of less than 20%.